THE MONTENERO INCLINE:
A FUNICOLAR EQUIPMENT MOVED BY SOLAR ENERGY

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INTRODUCTION

Small description of the equipment, its history, actual technical features and its role in the public transport system of Leghorn.

Few historical points

Montenero, is a little hill, in the southern neighbourhood of Leghorn, that is the second main city in Tuscany

Montenero is very famous for its sanctuary, consecrated and blessed by the Virgin Mary, and built in the XIV century.

From the hill's top it is possible to see a lovely view: You can see the town of Leghornm the Apuane Alps and the island of Gorgona.

The place is interesting and the transport request from the hill's foot to the top is large.
For this reason, the need of a specific transport mean was felt since the end of the XIX century and in August 1908 the funicular Railway was inagurated.

The railway

It has an average slope of 17%, with a maximum of 18.4%, a total length of 656 m. And a height difference of 110.9 m.

There are three bends with a bending radius of 180-250 metres; there is a single track, which in the central part becomes a double track to allow the two coaches to cross each other.

The equipment and its updates

THE ORIGINAL EQUIPMENT

The equipment installed in 1908, had tracks STJ type, very heavy wooden coachesm an electric motor with 30 Kw power

There was only a comunication system between the upper and the lower stations with two electric rings. The coaches had no communication system during the trip.

FIRST UPDATED

In 1972 , when the company managing became a public onem there were the fist alterations

In fact, at that time, it was seen that the equipment was too old-faschioned, so it was decided:

1. to change the coaches with the new lighter ones;
2. to use a new electric motor with more power (48 Kw)
3. to change the gear box, with a sealed one;
4. to buy a diesel motor with 60 CV power to manage the installation when the electric motor was out.

SECOND UPDATED

In1989, it was necessary to do other changes.

1. to improve the rail track conditions, after 80 years;
2. to give automations to the equipments to reduce people managing it, without reducing security conditions;
3. to allow handicapped people to use the equipment

These alterations were developed using three different italian companies:

A. Agudio for mechanical and automation items;
B. B.M.B for electric, electronic and automation problems
C. Cenedese company for civil engineering. In this phase a new track 50 DIN 5902, and a new fixing device (see fig. 1) were introduced.

The coofdination of the three companies, together with the developing of manu small works was performed by Azienda Trasporti Livornese, which was in charge of managing the railway.

The importance of the cable railway for the public transport system of Leghorn

Montenero's cable railway is the swiftest link between the two buroughs, which are at the foot and on the top of the Montenero hill.

It would be much more expensive to use buses, with diesel engines to move the same amount of passengers (9000 per day) on the same path: we would need daily six buses and six drivers. Instead we have only two operators on the railway, two coaches with no exhausted gas.

So the equipment automation was improved the economical management for an installation with no pollution problem.

The customers' targets to catch, in our casem are two:

1. people living on the Montenero hill, who need to reach the city-center for work, schools, pleasures etc.;
2. the touristic people, coming from other cities of Tuscany, to visit the place and the old sanctuary

In both cases, we have planned a strategy to obtain customs interest:

1. for local poeple, giving them good fares for passes;
2. for touristic people, giving them parking areas both at the foot of the hill, near the down station and in the PV-field area, which is 500 m. from the Sanctuary on the same level. Of

course the parking fares between down hill and tip hill parking areas have been planned to discourage the car's use and to promote the incline's use.

The Leghorn Transportation Agency (ATL) and the Electric Traction.

ATL manages the mobility problems in Leghorn aream both for trasport and for parking.
The transport service is developed mainly with traditional diesel bus (240 is the total amount in the fleet), but also vith the historical Montenero incline, which is the oldest electric traction device used in the company.

The parking service is developed both with parking meters and closed areas with gates and automatic cash box. In these areas can be rent electric car (20 Piaggio Electric Porter) and 5 moped (Celco Cip 025) with some bonus for *park and ride* users.

The company also has 7 electric Minibuses, type Gulliver Ep500 by Tecnobus, which are used in the center of the city, on routes particularly crowded or in the hospital, where low levels of atmosferic and noise pollution are a must.

The company is studying some PV field inside the parking area to feed electric cars and mopeds: the standard system will have around 30 Kwp of installed power and will be connected to the grid, managed by ENEL, the italian electric Company.

In pictures 2a/b and 3a/b electric bus and car can be seen.

PROJECT TECHNICAL DESCRIPTION

The photovoltaic (PV) field: features and structures

The power plant will consist of a 36.8 KWp solar generator installed in the area presently used as car parking, some 250 m. away from the uphill funicolar station (see fig. 4).

The solar generator will consist of a group of solar modules, 50 Wp each, series and parallel appropriately connected, on order to build up a +272Vdc –272Vdc voltage generator, with 23 strings in parallel, each string with 16+16 solar modules in seires with the centre connected ground (see fig. 5 and 6).

The solar modules are model PWX500 frame less produced by Photowatt International SA. The modules use high efficiency poly-crystal silicon cells with two protection diodes. The encapsulation of the cells between two sheets of tempered plate glass with durability. This technology offers the possibility to assure a 25 years life. The module dimensions are: mm. 462x1.042. The module is particurarly suited for building integration and has been used in previous building integrated systems with positive results.

The technical caracteristics of the solar generator are:

• current at maximum power point:	66.24 A
• voltage at maximum power point:	+272V –272V respect ground
• maximum power:	36.8 KWp
• energy yearly delivered	60MWh per year considering the losses

The solar generator installed on the roof of the parking area service buildingnext to the uphill funicular station will result in a sun-breaking roof with all the park services undeneath, presently missing and badly requested. The now unattended parking area will be attended instead and its safety greatly increased together with the safety of the solar plant against vandalism. A tourist bureau will be installed under PV roof.
Special care will be devoted to the integration of the structure in the environment. The integration on the building has been carefully studied above all according to the overall structural , esthetical and funcional characteristics.

The solar generator support structure will be made with dip zinc-coated steel elements appropriate to keep the solar modules 3.5 metres average above the ground levelm so as to avoid any interference with the vehicles. The structure has been designed using structural computer program and it has been sized to support 1m haight snow and 150 Km/h wind speed.

The solar frame less modules will be pre-assembled and wired at the factory in groups of 8 unitsm in order to obtain components, which can be easily tested, transported and installed in their final position. Two componentsm will be series connected in order to make a string of 16 mosules. The design allows easy replacement of any module eventually in failure. The replacemente of any modulecan be made without special tools.

A junction box receives the cabling of the modules connected in serie s in every string in order to make easy the connections. The junction box is equipped with an Hall effect sensor for the not invasive measure of the current. The value of the current in every string will be set by modem to the remote control system, in order to make possible the control of the wiring and the performances of single string directly by ATL.

A ground reference pole will be installed in appropriate location of the parking. To the same pole zill be connected all the òetallic structure of the building and the array support structures.

A 40 KWp dc/ac grid connected PMW modular converter uses one of the most advanced technologies in power electroncs, the IGBT inverter working on an intermediate frequency for MPPT control and with active power factor control. The inverter is housed in a room under the solar modules. The output is 380V-50Hz three phase.

A 208 m four conductors cable will connect the inverter with the electric substation of ENEL, the Italian electric autority close to the upper station of the funicular. The cable will first run on the wall sustaining the road and then buried in the Municipality owned land. Some 0.4% of the nominal power from the generator will be lost across the cable.

The incline movement devices

ATUAL DYNAMICS OF THE EQUIPMENT

In fig. 7 we can see the principal devices, which are in the upward station: the electric motor, the gear boz, the metallic disc with service and modulate brake, the driving and the driven wheels.

The motion, as you can see from fig. 8 and 9, starts from the electric motor, goes to the gear box and to the wheels; from the driven wheel the cable gores to the coach through a particular device named "oscillating coupling", which keeps its position thanks to the cable tension (when it lacks, some particular springs make the "oscillating coupling" go to the two microswitches, which stop the equipment).

In the equipment we have service and modulated Brake on the disc between gear box and driving wheel. The emergency brake can be actuated manually from the command deck either electrically or mechanically; in the same time the emergency brake can be actuated automatically for maximum speed, maximum electric current and for maximum rolling between driving shaft and driving wheel.

We have also on the driven wheel two switches, one for each coach, which must control the coaches checking some particular fixed points along the track.

A personal computer shows through the screen the position of each coach, the breaking diagram, the diagnostics of securitu devices switched onm the position of the failure on the equipment for a quick "debugging" (see fig. 10). A special S/W developed by B.M.B., an italian company from Vicenza, has allowed us to use all these options.

The new design solution: second movement device (emergency device) and modfications on the fist one (principal device)

The electic power production from the PV field will be poured into the ENEL grid, as 36.8 KWp of maximum powerm fro an annnual production evaluated in 60 MWh, losses considered.

With the above said production ratesm considering the irradiation figures in the area that span from 2.39 KWh/m2 day in December up to 6.92 KWh/m2 day in July with an average of 4.62 KWh/m2 day, we should have for the incline a production surplus in summer, while in winter time we eill have to catch power from the ENEL grid.

So the grid will be able to work as energy reservoir, taking energy in summer and giving back it in winter. In this scenario a "defaillance" of the ENEL grid would cause a sudden stop for the incline. For this reason we have planned to install a battery of sealed Pb accumulators, constituted by 200 modules, series appropiatelu connected, with a 300 Ah capacity at the dischargem in 10 hours, and nominal tension 400V.

The modification in the incline's movement device will be, see fig. 11-13, together with the previous described battery, an authomatic tyristors battery charger, type ANSALDO – BMB mod. BRG 310, installed in a specific rack and with protection management and check devices, to keep on charge the battery.

From the battery, loaded in the previous way, energy will be given to feed, in alternative:

1. A new d.c. motor, for the emergency movement (2nd movement device), with 30 KW power at 2400 RPM for a tension of 400 V, through a rack with resistences and meter. This motor will have a lower pover, than the fist one, and will allow to move the incline with a reduced speed (2m/s vs 4 m/s).
2. A d.c./d.c. converter, chopper like, to module the output tension, and consequently the speed, going to the existing dc motor (1st movement device). This jig will have a double meter to commute the d.c. electric motor on the static coverter (SCR), actually installed on the incline, or on the chopper.

In the solution 1 the new d.c. motor will make the hydraulic pump move, instead of diesel motor, very polluting, which is on work now: The pump will feed the hydraulic motor moving the big driving wheel.

All these variation s will effect the existing static path programmer forcing us to make it consistent with them. In the same way the actual hydraulic trasmission will be modified to make it compatible with the new d.c. motor.

The incline services, that are: (lighting of the stations and of the traced route, TV monitors and cameras, little gates, turnstiles etc.), for a total installed power of around 5 KW, will be fed by 60 Kva uninterrupted power supply (UPS), also when there is no grid

The services will be normally fed by the UPS, the grid tension will be used as reserve, it will intervene to feed the services through the Static By-Pass switch, only for the following faults:

1. Inverter failure;
2. Battery d.c. tension out of tolerance;
3. Outgoing overload very high;
4. Not sufficent cooling;

Usually the service will be fed through the chain:

- Battery charger rectifier;
- Battery;
- Static inverter;
- Static by-pass switch;

When the grid tension fail, the inverter will go on to feed the services without any discontinuity, taking the energy from the battery for the whole equipment required endurance (4 hours).

Up to the nminal power limits, the inverter will go on, until the battery tension reaches the lowest value of the allowable descharge. Under this value it stops itself automaticallu, switching the grid to the serivice loads through the by-pass switch.

DETAILED DESCRIPTION OF THE INNOVATIVE OBJECTIVE OF THE PROJECT

The innovative aspects for the whole project, "new moving device for the incline and solar generator", can be summarized as follows:

1. For the fist time in the world a **funicular is powered by sun** and there is another demostration of the capability of the PV power in the transport field;

2. The incline will not be obliged to use the ENEL grid for its service;

3. Any polluting device (diesel motor) will work any more at the funicular, **avoiding to produce neither atmosphere, nor noise pollution;**

4. Fully utilisation of the energy produced;

5. The PV array will be integrated into a sun-shading cover of the parking area thus **giving a double service to this component of the system** and saving space in an urban environment;

6. Use of the pre-assembled conponents ready for the direct installation on the final location;

7. Flexible design in view of economic repetition for such devices;

8. **Saving in the service running costs** by reducing the power supplied by the grid;

9. **Educational value for the people**, in order to push the use of renewable energies.

CONCLUSIONS

The project si now under developement. It has been planned to finish the design phase by May 99 ando to manufacture both the PV devices (solar panels, inverter, building structure) and the incline equipments by the end of October 99: The assembly and installation should last up to April 2000. Tess have been planned fo May-June 2000.
The total investment evaluated is 650 KEURO and will be financed by ATL, the companu managing the incline, the Leghorn municipalitym who owns both the incline and the Parking Area and by the European Community.

The evaluation of the R.O.I. (Return of investment) is quite hard, because there are many "returns", which cannot be quantified easily such as:

- The reduction of the atmospheric and noise pollution;
- The reduction fo electric grid power used, and consequently of oil consumption to produce grid power;
- The increase of the safety of the funicular considering that passengers will be carried to a station, whichever power "defaillance" will occur in the grid;
- The marketing promotion for the people in order to push renewable energies;

However, if we do not consider the above written parameters, the Returno Of Investiment (ROI) can be evaluated in this way.

$$R.O.I. = C/(D-M) = 9.29 \text{ YEARS}$$

Where:

C: Total costs (650 KEURO)
D: Yearly income (energy saving and parking revenues, 72 KEURO per year)
M: Year maintenance costs, approximately 2 KEURO per year

Where the lifespan of the installation may be assumed in 15 years, whitout considering tha abovewritten items and making them quantified in the previous formula, where they could reduce the ROI time.

The project shows a little contribute to save energy and to make better the environment, in a field –cable equipments -, where improvements can be planned.

FIGURES AND ANNEXES